jc685 U.S. PTO
03/01/00

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A

Attorney's Docket No. LRI-003PAT

PATENT

jc530 U.S. PTO 09/516328 03/01/00

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Box Patent Application
Assistant Commissioner for Patents
Washington. D.C. 20231

NEW APPLICATION TRANSMITTAL

Transmitted herewith for filing is the patent application of

Inventor(s): Paul S. Prevey III

For (title): **METHOD AND APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART**

CERTIFICATION UNDER 37 CFR 1.10

I hereby certify that this New Application Transmittal and the documents referred to as enclosed therein are being deposited with the United States Postal Service on this date March 1, 2000 in an envelope as "Express Mail Post Office to Addressee" Mailing Label Number EK303473334US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

Mark F. Smith
(Type or print name of person mailing paper)

Mark F. Smith
Signature of person mailing paper

1. Type of Application

This flew application is for a(n)

(check one *applicable item below)*

_X_ Original (nonprovisional)

____ Design

____ Plant

WARNING: Do, not use this transmittal for the filing of a provisional application.

NOTE: If one of the following 3 items apply, then complete and attach ADDED PAGES FOR NEW APPLICATION TRANSMITTAL WHERE BENEFIT Or A PRIOR US. APPLICATION CLAIMED and a NOTIFICATION IN PARENT APPLICATION OF THE FILING OF THIS CONTINUATION APPLICATION.

____ Divisional

____ Continuation

____ Continuation-in-part (C-I-P)

2. Benefit of Prior U.S. Application(s) (35 U.S.C. 119(e), 120, or 121)

NOTE: If The new application being transmitted is a divisional. continuation, or a continuation-in-part of a parent case, or where the parent case is an International Application which designated the U.S.., or benefit of a prior provisional application is claimed,, then check the following item and complete and attach ADDED PAGES FOP NEW APPLICATION TRANSMITTAL WHERE BENEFIT OF PRIOR US. APPLICATION (s) CLAIMED.

WARNING When the last clay of pendency of a provisional application falls on a Saturday, Sunday. or Federal holiday within the District of Columbia, any nonprovisional application claiming benefit of the provisional application must be filed prior to the Saturday. Sunday, or Federal holiday within the District of Columbia..

____ The new application being transmitted claims the benefit of prior U.S. application(s) and enclosed are ADDED PAGES FOR NEW APPLICATION TRANSMITTAL WHERE BENEFIT OF PRIOR U.S. APPLICATION(S) CLAIMED.

3. Papers Enclosed That Are Required for Filing Date under 37 CFR 1.53(b) (Regular) or 37 CFR 1.153 (Design) Application

_23_ Pages of specification
_6_ Pages of claims
_1_ Pages of abstract
_7_ Sheets of drawing
____ formal
_X_ informal

WARNING: DO NOT submit original drawings. A high quality copy of the drawings should be supplied when filing a patent application. The drawings that ace Submitted to the Office must be on strong, white, smooth, and non-shiny paper and meet the standards according to Section 1.84. If corrections to the drawings are necessary, they should be made to the original drawing and a high-quality copy of The corrected original drawing then submitted to the Office. Only one copy is requited or desired,

NOTE: "Identifying indicia, if provided, should include the application number or the title of the invention,, inventor's name. docket number (if any), and the name and telephone number of a person to call! If the office is unable to match the drawings to the proper application.. This information should be placed on tie back of each sheet of drawing a minimum distance of 1.5 cm. (5/8 inch) down tram the top of the page.

(Complete the following, if applicable)

______The enclosed drawing(s) are photograph(s), and there is also attached a "PETITION TO ACCEPT PHOTOGRAPH(S) AS DRAWING(S)".

4. Additional papers enclosed:

____ Preliminary Amendment
____ Information Disclosure Statement (37 CFR 1.98)
____ Form Information Disclosure Citation (PTO-1449)
____ Citations
____ Declaration of Biological Deposit
____ Submission of "Sequence Listing," computer readable copy and/or amendment pertaining thereto for biotechnology invention containing nucleotide and/or amino acid sequence.
____ Authorization of Attorney(s) to Accept and Follow Instructions from Representative
____ Special Comments
_X_ Other

5. Declaration or oath

__X__Enclosed

Executed by:

_X__ The inventor(s)

_____ legal representative of inventor(s). 37 CFR 1.42 or 1.43.

_____joint inventor or person showing a proprietary interest on behalf of inventor who refused to sign or cannot be reached.

_____ This is the petition required by 37 CFR 1.47 and the statement required by 37 CFR 1.47 is also attached. See item 13 below for fee.

_____ Not Enclosed.

____Application is made by a person authorized under 37 CFR 1.41(c) on behalf of a(l *the above named inventor(s).*

(The declaration or oath, along with the surcharge required by 37 CFR 7.76(e) can be filed subsequently).

___ Showing that the filing is authorized.
(not required unless called into question. 37 CFR 7.47(d))

6. Inventorship Statement

WARNING: ıf the n-fled ınventors are each not the ınventors of all the claıms an explanatıon, includıng the ownershıp of the varıous clams at the tıme the last claımed ınventıon was made, should be submıtted.

The Inventorship for all the claims in this application are:

_X_ The same.

___ Not the same. An explanation, including the ownership of the various claims at the time the last claimed invention was made___ is submitted.

___ Will be submitted.

7. Language

NOTE: *An applıcation ıncludıng a sıgned oath or declaratıon may be filed ın a language other than Englısh. A verified Englısh translatıon of the non-Englısh language applıcatıon and the processıng fee of $130.00 required by 37 CFR l.1.17(k) ıs required to be filed wıth the applıcation, or wıthın such time as may be set by the Office 37 CER 1.62(d).*

NOTE: *A non-Englısh oath or declaratıon ın the Form provıded or approved by the PTO need not be translated. 37 CFR 1.69(b).*

_X_ English

_____ Non-English

___ The attached translation is a verified translation. 37 CFR 1.52(d).

8. Assignment

____ An assignment of the invention to____

____

is attached. A separate_____ "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" or _____ FORM PTO 1595 is also attached.

______will follow.

NOTE' *"'ıf an assignment ıs submitted wıth a new applıcatıon, send two separate letters-one for the applıcatıon and one for the assıgnment." Notıce of May 4, 1990 (1114 0.0. 77-78).*

WARNING: *A newly executed "CERTIFICATE UNDER 37 CFR 3.73(b)" must be filed when a contınuatıon-ın-part applıcatıon ıs filed by an assıgnee. Notıce of Aprıl 30, 1993, 1150* 0.0.62-64.

9. **Certified Copy**

Certified copy(ies) of application(s)

country	appln. no.	flied
country	appln. no.	flied
country	appln. no.	filed

from which priority is claimed

_____ is (are) attached.

_____ will follow.

NOTE: The *foreign application* forming the basis for the claim *for priority must* be interred to *in the oath or declaration. 37 CFR 1.55(a)* and *163*

10. Fee Calculation (37 CFR 1.16)

A. __X__ Regular application

CLAIMS AS FILED

Number filed	Number Extra		Rate	Basic Fee 37 CFR 1.16(a) $690.00
Total Claims (37 CFR 1.16(c))25- 20= 5		x	$18.00	$ 90.00
Independent Claims (37 CFR 1.16(b)) 6 - 3 =	3	x	$ 78.00	234.00
Multiple dependent claim(s), if any (37 CFR 1.16(d))		+	$260.00	0.00

_____ Amendment canceling extra claims enclosed.

_____ Amendment deleting multiple-dependencies enclosed.

_____ Fee for extra claims is not being paid at this time.

NOTE:If the fees for extra claims are not paid on fling they must be paid or the claims canceled by amendment, prior to the expiration of the time set for response by the Patent and Trademark office in any notice of deficiency. 37 CFR 1.16(d).

Filing Fee Calculation $ 1,014.00

B. _____ Design application
($330.00 - 37 CFR 1.16(f))
Filing Fee Calculation $______________

C. _____ Plant application
($540.00 - 37 CFR 1.16(g))
Filing fee calculation $______________

11. Entity Statement(s)

__X_ Verified Statement(s) that this is a filing by a small entity under 37 CFR 1.9 and 1.27 is (are) attached.

WARNING: "Status as a small entity in one application or patent does not affect any other application or patent, including applications or patents which are directly or indirectly dependent upon the application or patent in which the status has been established. A non provisional application claiming benefit under 35 U.S.C. 719(e), 120,121 or 365(c) of a prior application may rely on a verified statement filed in the prior application if the nonprovisional application includes a reference to a verified statement in the prior application or includes a copy of the verified statement filed in the prior application if status as a small entity is still proper and desired." 37 CFR 1.28(a).

(complete the following, if applicable)

_____ Status as a small entity was claimed in prior application _____/____________ from which benefit is being claimed for this application under:

35 U.S.C. _____ 119(e),
_____ 120,
_____ 121,
_____ 365(c),

and which status as a small entity is still proper and desired.

_____ A copy of the verified statement in the prior application is included.

Filing Fee Calculation (50% of **A**, **B** or **C** above) $ 507.00

NOTE: Any excess of the full fee paid will be refunded if a verified statement and a refund request are Med within 2 months of the date of timely payment of a full fee. The two-month period is not extendable under 1.136, 37 CFR 1.28(a).

12. Request for International-Type Search (37 CFR 1.104(d))

(complete, if applicable)

_____ Please prepare an international-type search report for this application at the time when national examination on the merits takes place.

13. Fee Payment Being Made at This Time

_____ Not Enclosed

_____ No filing fee is to be paid at this time.
(This and the surcharge required by 97 CFR 1.16(e) can be paid subsequently.)

__X__ Enclosed

__X_ Basic filing fee $ 507.00

_____ Recording assignment
($40.00; 37 CFR 1.21(h))
(See attached "COVER SHEET FOR ASSIGNMENT ACCOMPANYING NEW APPLICATION".) $ 0.00

_____ Petition fee for filing by other than all the inventors or person on behalf of the inventor where inventor refused to sign or cannot be reached.
(37 CFR 1.47 and 1.17(h)) $________

Total fees enclosed: $ 507.00

14. Method of Payment of Fees

_X__ Check in the amount of $507.00

_____ Charge Account No. _____________ in the amount of $_____________
A duplicate of this transmittal is attached.

15. Authorization to Charge Additional Fees

WARNING
If no fees are to be paid on filing. The following items should not be completed.

_____The Commissioner is hereby authorized to charge the following additional lees by this paper and during the entire pendency of this application to Account No. __________

_____ 37 CFR 1.16(a), (f) or (g) (filing fees)

_____ 37 CFR 1.16(0), (c) and (d) (presentation of extra claims)

_____ 37 CFR 1.16(e) (surcharge for filing the basic filing fee and/or declaration on a date later than the filing date of the application)

_____ 37 CFR 1.17 (application processing tees)

_____ 37 CFR 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 CFR 1.311(b))

16. Instructions as to Overpayment

_____ Credit Account No. _____________ Refund

Mark F. Smith

Reg. 32,437

(513)936-8537 Phone
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10921 Reed Hartman Highway
Suite 316
Cincinnati, Ohio 45242

_X__ **Incorporation by reference of added pages**

(check the following item if the application in this transmittal claims the benefit of prior U.S. application(s) (including an international application entering the U.S. stage as a continuation, divisional or C-I-P application) and complete and attach the ADDED PAGES FOR NEW APPLICATION TRANSMITTAL WHERE BENEFIT OF PRIOR U.S. APPLICATION(S) CLAIMED)

_____ Plus Added Pages for New Application Transmittal Where Benefit of Prior U.S. Application(s) Claimed

Number of pages added_______

__X_ Plus Added Pages for Papers Referred to in Item 4 (See Items 5 and 11) above

Number of pages added__4____

_____ Plus "Assignment Cover Letter Accompanying New Application"

Number of pages added__0____

_____**Statement Where No Further Pages Added**

(if no further pages form a part of this Transmittal, then end this Transmittal with this page and check the following item.)

__X_ This transmittal ends with this page.

PATENT

Attorney's Docket No. LRI-003PAT

Applicant(s): Paul S. Prevey III

For: METHOD AND APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART

VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) AND 1.27 (b)-INDEPENDENT INVENTOR(S)

As a below named inventor, I hereby declare that I qualify as an independent inventor, as defined in 37 CFR 1.9(c), for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code, to the Patent and Trademark Office, with regard to the invention entitled **METHOD AND APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART** described in the specification filed herewith.

I further declare that I have not assigned, granted, conveyed or licensed, and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who could not be classified as an independent inventor under 37 CFR 1.9(c), if that person had made the invention, or to any concern that would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

X no such person, concern, or organization.

___ persons, concerns or organizations listed below.

FULL NAME:____

ADDRESS:____

____

___ Individual ___ Small Business Concern ___ Nonprofit Organization

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small business entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Name of Person Signing: Paul s. Prevey III having
a residence at: 6325 Hunters Trail, Cincinnati, Ohio 45246 U.S.A.

SIGNATURE ________ Date 3/6/00

METHOD AND APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART

Related Patent Applications

The present Application deals with related subject matter in co-pending U.S. patent application entitled METHOD FOR REDUCING TENSILE STRESS ZONES IN THE SURFACE A PART, filed on the same day as the present application and having the same inventor in common.

Background of the Invention

This invention relates to a method and an apparatus for imparting residual stress in the surface of a part and, more particularly, to a method of inducing a selected compressive residual stress distribution within the surface of a part to improve fatigue and stress corrosion performance of the part and an apparatus for implementing the method.

Surface residual stresses are known to have a major effect upon the fatigue and stress corrosion performance of component parts. Tensile residual stresses, which can develop during manufacturing processes such as grinding, turning, or welding are well known to reduce both fatigue life and increase sensitivity to corrosion-fatigue and stress corrosion cracking of the part. Further, many parts that are subjected to high dynamic stresses or have areas where stress concentrations occur, such as blades and the rotor disks of turbo machinery, are prone to crack initiation and relatively rapid crack growth. The blades typically comprise an airfoil portion, a platform for partially defining a surface for fluid flow there over when the blade is mounted to the rotor disk, and a root portion having retention grooves which engage in corresponding axially extending complementary grooves of the disk. During engine operation, the rotor disk and the blade are subjected to large centrifugal loads that produce high dynamic stresses that may cause high cycle fatigue along portions of the rotor disk and the blade causing cracking and possible failure of the part. Further, the leading edge of the airfoil is often subjected to damage caused by the impact of foreign objects in the fluid stream. Such impact often results in cracks

forming along the leading edge that may result in failure of the blade.

It is well known that compressive residual stresses induced in the surface of a part can increase fatigue life and reduce susceptibility to corrosion-fatigue and stress corrosion cracking. There are currently several methods used in industry for inducing compressive stress in the surface of a metal part and the particular method selected has been dependent on factors such as the dimensions and shape of the part, its strength and stiffness, the desired quality of the finished surface, the desired physical properties of the finished part, and the expense of performing the operation.

One method commonly used in industry to induce compressive stress in the surface of a part is shot peening, whereby a plurality of metallic or ceramic pellets are projected mechanically or through air pressure to impinge the surface of the part. While such a method is relatively inexpensive and is preferred for many applications, shot peening is unacceptable for parts requiring a superior finish or requiring a greater depth of compressive stress penetration and has also been found to be unacceptable for parts requiring localized or well defined compressive stress regions. Further, for parts such as a rotor disk for use in turbo machinery, the bore surfaces of the rotor disk are subjected to low levels of plastic strain (typically between about 0.2% to about 0.5%) when the rotor disk is accelerated to full speed. If the surfaces have been highly cold worked, such as during shot peening, the cold worked compressive surface material will not yield in tension while the lower yield strength interior material will yield during engine operation. On unloading, such as when the rotor speed is reduced, the surface is driven into tension and will remain in tension, reducing its fatigue life, for the remaining life of the component.

Another method commonly used in industry to induce compressive stress in the surface of a part is laser shock peening, whereby multiple radiation pulses from high power pulsed lasers produce shock waves on the surface of the part to produce a high

magnitude localized compressive stress within a particular region. Unfortunately, however, laser shock peening is relatively expensive and time consuming making it unacceptable for many applications.

A method which have been developed and is widely used in industry to improve surface finish, fatigue life, and corrosion resistance by deforming the surface of a part is burnishing whereby a rotary or sliding burnishing member is pressed against the surface of the part in order to compress the microscopic peaks in the surface into adjacent hollows. Burnishing operates to develop compressive stresses within the part by yielding the surface in tension so that it returns to a state of compression following deformation.

The burnishing apparatus utilized for working the surface of a part typically comprise a plurality of cylindrical rollers or balls which contact the surface of the part with sufficient pressure to induce a compressive stress therein. Unfortunately, sharp surface demarcation typically exists along the boundaries of the burnished area often resulting in tensile residual stresses being formed along such boundaries. As disclosed herein, it has been found that gradually reducing the pressure being exerted by the burnishing member to reduce the magnitude of compression at the boundaries will reduce the build up of tensile residual stress. Further, it has been found that by controlling the compressive residual stress distribution and the magnitude of compression, the tensile stress distributions within a part may be offset or distributed in such a manner as to optimize the fatigue and/or stress corrosion performance of the part. Until now, however, a method and apparatus have not been developed that permitted the residual stress distributions and the magnitude of compression to be controlled in such a manner as to optimize fatigue performance for a specific applied stress distribution.

Consequently, a need exists for a relatively inexpensive, relatively time efficient method and apparatus for implementing the method for improving the physical properties of a part by inducing a layer of compressive stress in the surface of the part, which is

effective for use with complex shaped surfaces, and which permits the magnitude of compression and the residual stress distributions to be produced on a surface to achieve optimum fatigue performance and stress corrosion performance of the part.

Summary of the Invention

The novel method of the present invention for inducing a layer of compressive residual stress along the surface of a part comprises the steps of selecting a region of the part to be treated; selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region of the part; exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress; and varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface.

In another preferred embodiment of the invention, the step of exerting pressure against the surface of the selected region included performing a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface of the selected region of the part to produce a zone of deformation having a deep layer of compression.

In another preferred embodiment of the invention, the pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 5.0%.

In another preferred embodiment of the invention, the pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 3.5%.

In another preferred embodiment of the invention, whereby the step of exerting pressure on the surface of the part is performed by a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface

of the selected region to induce a deep layer of compression within the surface having associated cold working of less than about 5.0 percent.

In another preferred embodiment of the invention, whereby the step of exerting pressure on the surface of the part is performed by a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface of the selected region to induce a deep layer of compression within the surface having associated cold working of less than about 3.5 percent.

In another preferred embodiment of the invention, whereby the selected pattern operates to vary the spacing between the zones of deformation to produce the desired residual stress distribution.

In another preferred embodiment of the invention, the step of selecting the magnitude of compression includes the step of programming a control unit to automatically adjust the pressure being exerted against the surface of the part.

In another preferred embodiment of the invention, the step of exerting pressure against the surface of the selected region includes performing a burnishing operation and the step of programming a control unit to control the direction of movement of a burnishing member to produce the desired stress distribution.

In another preferred embodiment of the present invention the step of varying the pressure being exerted against the surface of a part includes the steps of programming a control unit to adjust the pressure being exerted by a burnishing member against the surface of the part, and programming the control unit to direct the burnishing member over the part in a selected pattern to obtain the desired residual stress distribution.

In another preferred embodiment of the present invention, the step of varying the pressure being exerted against the surface of a part includes the step of gradually varying the magnitude of compressive stress in the areas immediately adjacent to the boundaries of the selected region.

In another preferred embodiment of the present invention, a method of inducing a layer of compressive stress in the surface of a part comprises the steps of inducing a deep layer of compression within the surface and inducing a more shallow layer of compressive stress within the surface of the selected region.

In another preferred embodiment of the present invention, a method of inducing a layer of compressive stress in the surface of a part comprises the steps of inducing a deep layer of compression within the surface and removing a layer of material along the surface being in low compression or tension.

In another preferred embodiment of the present invention, the method of inducing a layer of compressive stress in the surface of a part comprises the steps of programming a control unit to adjust the pressure being applied by the burnishing member against the surface of the part; programming the control unit to direct the burnishing member over the part in a predetermined pattern to induce a layer of compressive stress in the surface of the part; and applying a secondary process to impart a relatively shallow layer of compressive residual stress along the surface of the part to produce the desired residual stress distribution.

The novel apparatus for implementing the method of the present invention utilizes a burnishing process for inducing a layer of compressive residual stress having a preselected magnitude of compression and a desired stress distribution. In particular, the burnishing apparatus comprises a burnishing member for applying pressure against the surface of the selected region of the part to produce a zone of deformation having a deep layer of compression and a preselected magnitude within the surface. The burnishing apparatus further comprises means for moving the burnishing member in a predetermined pattern across the selected region to produce a desired residual stress distribution.

In another preferred embodiment of the invention the burnishing apparatus for implementing the burnishing method of the subject invention comprises a burnishing

member for applying pressure against the surface of a part to induce a layer of compressive stress therein; means for adjusting the pressure being applied against the surface of the part by the burnishing member; and means for directing the burnishing member over the surface of the part in a predetermined pattern to provide the desired residual stress distribution.

In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention is coupled to a control unit for automatically controlling the movement, position, and application pressure of the burnishing member.

In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention comprises means for supplying a constant flow of fluid to support the burnishing member.

In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention comprises magnetic means for maintaining the burnishing member within the socket.

Another preferred embodiment of the invention is a blade for use in turbo machinery having having a desired stress distribution.

Another preferred embodiment of the invention is a rotor disk for use in turbo machinery comprising selected regions having desired stress distributions.

Another preferred embodiment of the invention, a part selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like comprises regions of compressive residual stresses having predetermined stress distributions.

Another preferred embodiment of the invention, a part selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like treated by the

method comprising the step, or a combination of steps, of the present invention.

. A primary object of this invention, therefore, is to provide a method and an apparatus for implementing the method of providing a part with an improved finish and with improved physical properties.

Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer on the surface of a part.

Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer that varies in magnitude of compression across the part in a predetermined pattern.

Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer having a well defined stress distribution.

Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer having a predetermined stress distribution.

Another primary object of this invention is to provide a method for forming a part having deep compression with a minimal amount of cold working and surface hardening.

Another primary object of this invention is to provide a method of inducing a relative deep layer of compressive stress and a relative shallow layer of compressive stress in the surface of the part.

Another primary object of the invention is to provide a burnishing apparatus that permits the pressure being exerted on the surface of a part to be varied to produce regions having residual stress distributions of arbitrary shape and magnitude of compression.

Another primary object of the invention is to provide a burnishing apparatus comprising means for automatically adjusting the burnishing force and the corresponding

pressure being exerted against the surface of a part that increases on the high points encountered along the surface and decreases on the low points encountered along the surface of the part.

Another primary object of this invention is to provide an apparatus having a burnishing member within a socket and magnetic means for maintaining the burnishing member within the socket.

Another primary object of this invention is to provide an apparatus having a burnishing member within a socket which can be easily removed and inserted into place within the socket.

Another primary object of this invention is to provide a blade for use in turbo machinery having relatively good fatigue and stress corrosion performance.

Another primary object of this invention is to provide a rotor disk for use in turbo machinery having relatively good fatigue and stress corrosion performance.

Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer on the surface of a part which is relatively inexpensive.

Another primary object of this invention is to provide a blade for use in turbo machinery comprising regions of compressive residual stresses having predetermined stress distributions.

Another primary object of this invention is to provide a blade for use in turbo machinery having a compressive stress layer that varies in magnitude of compression across the part.

Another primary object of this invention is to provide a disk for use in turbo machinery comprising regions of compressive residual stresses having predetermined patterns of magnitude of compression and residual stress distribution.

Another primary object of this invention is to provide a part selected from the

group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like comprising regions of compressive residual stresses having predetermined patterns of magnitude of compression and residual stress distributions.

These and other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

Brief Description of the Drawings

FIG, 1 is a schematic block diagram illustrating the method of the present invention;

FIG. 2 is a graph illustrating the predicted longitudinal residual stress distribution, following 2.1% plastic strain, of a part having been treated by the method of shot peening and a part having been treated by the method of burnishing;

FIG. 3 is a graph illustrating the percent of cold work and yield strength distribution of a part having been treated by the method of shot peening and a part having been treated by the method of burnishing;

FIG. 4 is a schematic view of a generally rectangular region being treated by the method and apparatus of the invention for inducing a desired residual stress distribution and magnitude of compression whereby the pressure being exerted (force normal to the surface) against the surface is varied in two directions;

FIG. 5 is a schematic view of another region being treated by the method and apparatus of the invention for inducing a desired residual stress distribution and magnitude of compression whereby the density of the burnishing pattern is varied in the one direction;

FIG. 6 is a schematic view of another region being treated by the method and apparatus of the invention for inducing a desired residual stress distribution and magnitude of compression whereby the density of the burnishing pattern is varied in the

two directions.;

FIG. 7 is a schematic view of another region being treated by the method and apparatus of the invention for inducing a desired residual stress distribution and magnitude of compression, such as around a bolt hole, whereby the pattern is a symmetrical pattern;

FIG. 8 is a graph illustrating the residual stress distribution induced in the surface of a part in the direction of burnishing (parallel) and in the transverse direction (perpendicular);

FIG. 9 is a graph illustrating the percent cold work distribution for the burnishing operation shown in **FIG. 8**;

FIG. 10 is a diagrammatic view of the burnishing apparatus for implementing the method of the present invention;

FIG. 11 is a diagrammatic view of the socket of a preferred embodiment of the burnishing apparatus of the present invention showing magnetic means for maintaining the burnishing member within the socket;

FIG. 12 is a bottom diagrammatic view of the socket of **FIG. 11** with the burnishing member removed;

FIG. 13 is a diagrammatic view of the socket of **FIG. 11** showing the magnetic field lines for maintaining the burnishing member within the socket; and

FIG. 14 is a partial perspective view of a blade and a rotor disk of the present invention.

Detailed Description of the Preferred Embodiment

The present invention relates to a method and an apparatus for implementing the method of inducing a layer of compressive residual stress along the surface of a part. In a preferred embodiment of the invention, as shown in **FIG. 1**, the method of the present invention comprises the steps of selecting a region of the part to be treated; selecting the

magnitude of compression and the residual stress distribution to be induced along the surface of the selected region, such as for example by finite element analysis; and inducing a layer of compressive residual stress along the surface of the selected region having the desired magnitude of compression and stress distribution.

It has been found that for parts having a surface that has been substantially cold worked, such as a rotor disk for turbo machinery that has been treated by the process of shot peening, the cold worked compressive surface material will typically not yield in tension, such as during high speed operation, while the lower yield strength interior material will yield. On unloading of the part, such as when the speed of revolution of the rotor disk slows, the surface of the part is driven into tension and will remain in tension, reducing the fatigue life, throughout the parts remaining life. Referring to **FIG. 2**, the inversion into tension of a surface of a part having been treated by the method of shot peening is shown compared to a surface of a part having been treated by the method of burnishing, each having a 2.1% plastic strain single cycle. Referring to **FIG. 3**, the corresponding percent of cold work and yield strength distribution are shown. As illustrated, upon unloading, the part that underwent the method of shot peening may actually invert from compression into a relative high level of tension, if a yield strength gradient exists, thereby significantly reducing the fatigue life of the part.

Accordingly, it has been found that the preferred method of the present invention for improving the surface finish, fatigue life, and stress corrosion resistance of a part is burnishing, whereby a rotary or sliding member is pressed against the surface of the part in order to compress the microscopic peaks in the surface into adjacent hollows. Such compression develops compressive stresses within the part by yielding the surface in tension so that it returns to a state of compression following deformation. As shown in U.S. Patent No. 5,826,435, by the same inventor and incorporated herein by reference, by cold working the surface less than about 3.5%,and preferably less than about 2.0%,

results in layer retention of compressive residual stress at elevated temperature, less rapid relaxation under cyclic loading, and minimizes the alteration of the residual stress field during tensile or compressive overload than conventional cold working and surface hardening processes. Accordingly, the method of the present invention is shown in **FIG. 1** and preferably utilizes the process of burnishing to provide deep compression with a minimal amount of cold working and surface hardening. In particular, the region to be burnished along the surface of the part is first defined and a burnishing apparatus having a single-point of contact burnishing member is pressed against the surface of the part to create a zone of deformation producing a relatively deep layer of compression within the surface. The burnishing member is then passed in a predetermined pattern across the region. Preferably, the pattern of burnishing is such that the zones of deformation formed by each pass of the burnishing member do not overlap. As disclosed in U.S. Patent No. 5,826,435, applying a single-pass, or multiple passes having a reduced compressive pressure, produces compressive residual stresses following tensile deformation of the surface having deep compression with minimal cold working.

In another preferred embodiment of the invention, the method further comprises the steps of determining the optimum magnitude of compression to be induced at particular points along the surface of the selected region by controlling the pressure being exerted by the burnishing member. In another preferred embodiment of the invention, the method comprises the steps of varying the pattern of burnishing to produce a desired residual stress distribution. In another preferred embodiment of the invention, the method further comprises the steps of programming a control unit, such as a computer or numerical controller, to automatically regulate the burnishing force being applied to the burnishing member thereby controlling the pressure being exerted against the surface of the part and the corresponding magnitude of compression being induced by the burnishing apparatus. The control unit may also be programmed to control the direction of

movement of the burnishing apparatus to produce the desired residual stress distribution.

The particular pressure and the pattern of burnishing for a part may be selected whereby the magnitude of compression and the residual stress distribution optimizes the fatigue performance of the part. For illustration, as shown in **FIG. 4**, a rectangular burnishing region is selected and the burnishing member is pressed against the surface of the part in a particular (raster) pattern, as shown by the arrow indicating the path of the burnishing member. The normal force (Fz) being applied to the burnishing member is varied to increase or decrease the pressure being exerted against the surface of the part. While **FIG. 4** shows a linear variation in the normal force and the corresponding pressure being applied against the surface, parallel (X-direction) and perpendicular (Y-direction) to the direction of burnishing, it should now be apparent to those skilled in the art that the pattern of burnishing and the form and rate of reduction or increase in pressure being exerted against the surface can be controlled to provide a wide variety of residual stress distributions and magnitude of compression.

Referring to **FIG. 5**, another illustration of the method of the present invention is shown whereby variations in residual stress distribution may also be achieved by varying the pattern of burnishing, independently or in conjunction with variations in burnishing pressure. As shown, the spacing along the X-direction, perpendicular to the direction of travel of the burnishing member, has been varied to increase and decrease the spacing between each pass of the burnishing member thereby changing the density (Dx) of burnishing. As shown, the spacing between each pass of the burnishing member varies linearly, however, it should now be apparent to those skilled in the art that other burnishing patterns may be selected to produce the desired residual stress distribution.

Referring to **FIG. 6**, another pattern of burnishing is shown whereby the spacing density (Dx) is varied in two dimensions (X and Y directions) as a function of the length of the burnishing pass, in order to produce the desired stress distribution for the part being

burnished.

Referring to **FIG.** 7, another pattern of burnishing is shown whereby a region is designated and the magnitude of compression and the residual stress distribution is selected that optimizes the fatigue performance of the part. As shown, the residual stress distribution has a symmetrical pattern such as what would be preferred for use around bolt holes or for "feathering" in a state of compressive stress in the fillet area of a rotor disk. It should now be apparent to those skilled in the art that the burnishing pressure, the density of burnishing, and the pattern of burnishing can be varied to produce the desired residual stress distribution and magnitude of compression for a part for a specific engineering application.

In another preferred embodiment of the invention, the method of inducing a layer of compressive residual stress along the surface of a part includes the step of using a secondary process, such as shot peening, grit blasting, tumbling or other similar abrasive impact processes to induce a shallow layer of compressive residual stress near the surface of the part following burnishing. As shown in **FIGS. 8** and **9**, burnishing of a surface inherently produces a Hertzian loading of the surface resulting in maximum compression beneath the surface of the work piece. The residual stress at the surface can be near zero or even tensile, and is a function of the direction of the burnishing operation. The surface residual stress is typically less compressive in the direction of burnishing (parallel) than in the transverse direction (perpendicular) due to the effect of displacement of material laterally during passage of the burnishing member. The presence of lower compression at the surface has been found to allow the initiation of fatigue cracks at the surface of the part. Although these cracks are arrested as they propagate deeper into the more highly compressive material, the presence of surface cracks and the stress intensity factor associated with them is highly undesirable. It has been found that the method of this invention comprising the steps of burnishing a part in combination with the secondary

process identified herein above provides surface compression as well as deep compression resulting in a part having superior resistance to surface crack initiation and propagation. In another embodiment of the invention, the method of the present invention comprises the step, in conjunction with the first step of burnishing, of removing a layer of low compression by electropolishing, etching or other similar means that will not induce a state of stress or through mechanical means, such as low stress grinding, polishing, tumbling, or other such means, which will induce a state of shallow compressive stress.

Referring to **FIG. 10**, a preferred embodiment of the burnishing apparatus **100** for implementing the burnishing method of the subject invention is shown comprising a generally cylindrical socket **102** which conventionally mounts to a support **104** of any particular description typically used for supporting burnishing tools which is attached to a conventional machine tool fixture (not shown). In a preferred embodiment of the invention, the support **104** is coupled to the socket **102** and provides means for imparting a normal force **F** to a burnishing member **106** to effect the proper burnishing pressure sufficient to deform the surface **108** of the part **110**.

The socket **102** includes a seat **112** adapted to the surface of the burnishing member **106** which is disposed within the seat **112**, and an inner chamber **114**. The size of the seat **112** is determined by the size and shape of the burnishing member **106** and is selected to provide a small clearance **116** between the seat **112** and the burnishing member **106**. As shown, the support **104**, in cooperation with the machine tool fixture, is adapted for controlling the movement of the socket **102** and includes means for forcing the socket **102** and the burnishing member **106** against the surface **108** of the part **110** being burnished. Without departing from the invention, it should now be apparent to those skilled in the art that various apparatus may be constructed to allow the socket to be moved to various positions or to allow the part being treated to rotate or pass in contact with the burnishing member in such a way that the selected region is burnished

using the method of the present invention.

The socket **102** is further provided with a fluid passage **118** in flow communication with the seat **112** and extends from the seat **112** through the inner chamber **114** to a fitting (not shown) for connecting to a positive displacement pump **120** for providing a constant volumetric flow of fluid from a fluid supply **122** to the seat **112**. The fluid supply **122** may be an external supply (not shown) or may be in the form of a sump **124**, as shown, thereby forming a closed-loop fluid system. The positive displacement pump **120** is preferably coupled to a direct current (DC) electric motor **126** and a fast acting motor speed control **128**. The motor speed control **128** functions to maintain a constant angular velocity of the motor **126** to sustain the constant volumetric fluid flow to the socket **102** regardless of any changes in fluid pressure. A pressure sensor **130**, such as a pressure transducer, is connected to the fluid passage **118** for monitoring fluid pressure and is coupled to a control unit **132**, such as a computer or a numerical controller, which is also coupled to either a position regulator **134**, such as a spring, or a pressure regulator **136**, such as a hydraulic or pneumatic system, that operate with the burnishing member **106** to provide the proper burnishing pressure being exerted against the surface **108** of the part **110**.

To understand how the elements of this invention described are interrelated, the operation of the burnishing apparatus **100** will now be described. During operation, fluid, such as a lubricating fluid, is fed under pressure from the fluid supply **122** by use of the positive displacement pump **120** through the fluid passage **118** and into the inner chamber **114**. The fluid in the inner chamber **114** is then fed under pressure around the burnishing member **106** through clearance **116** to force the burnishing member **106** outwardly. The lubricating fluid flows around the outer surface of the burnishing member **106** to permit the burnishing member **106** to float continuously upon a thin film of fluid. The socket **102** is then advanced towards the surface **108** of the part **110** by operation of the support

and the machine tool fixture (not shown) until the forward most portion of the burnishing member **106** makes contact with the surface **108**. By further adjusting the speed of the motor, a desired amount of lubrication fluid will flow around the burnishing member **106** and be transferred onto the surface **108** of the part **110** to provide the desired lubrication and cooling for the burnishing operation. During burnishing, the further most portion of the burnishing member **106** contacts the surface **108** of the part **110** causing the burnishing member **106** to move inwardly into the socket **102** thereby reducing the clearance **116** between the burnishing member **106** and the socket **102** thereby increasing the pressure of the fluid in the fluid passage **118**. The increase in fluid pressure is detected by the pressure sensor **130** which is coupled to the control unit **132** that functions to adjust the force **F** being applied to the burnishing member **106** to maintain a constant or controlled variable burnishing pressure against the surface **108**. It should now be apparent to those skilled in the art that the constant flow burnishing apparatus **100** of the present invention, unlike conventional constant pressure burnishing apparatus that follow the surface topography of the part, automatically increases the force **F** being applied to the burnishing member **106**, and the corresponding pressure being exerted against the surface **108**, on high points and decreases on low points along the surface **108**. Accordingly, the pressure or the compressive force exerted on the surface **108** of the part **110** by the burnishing member **106** can be precisely regulated to provide optimum surface finish and uniform burnishing of the part.

In a preferred embodiment of the invention, the proper pressure or compressive force to be applied to the surface **108** of the part **110** during the burnishing operation is provided by using the position regulator **134** whereby the force **F** being applied to the burnishing member **106** is a function of the position of the socket **102**. As shown, the position regulator **134** includes a spring means **140**, such as a coil spring, deflection members, or Belleville washers, having a known spring characteristic, which compresses

or expands axially to apply a given normal force **F** to the burnishing member **106**. Because the burnishing member **106** is coupled through the spring means **140**, the force **F** being applied to the burnishing member **106** and the resulting pressure being exerted on the surface **108** of the part **110** can be accurately controlled by positioning (moving) the socket **102** using the conventional machine tool fixture (not shown). The control unit **132** operates with a feed back signal from the pressure sensor **130** to achieve closed loop control of the force **F** and the corresponding pressure being exerted on the surface by the burnishing member **106**.

Preferably the machine tool fixture supporting the socket **102** is a "three-axis" machine that provides for linear motion along mutually orthogonal axis of a fixed coordinate system.

It should now be apparent to those skilled in the art that by using a programmable control unit **132** which is configured to continuously track the position of the burnishing member **106**, the socket **102** can be accurately positioned and moved in a selected pattern. Further, in combination with passing the burnishing member is a selected pattern across the surface of the part, the pressure being exerted against the surface may be varied to obtain a region having the desired residual stress distribution and magnitude of compression.

In another preferred embodiment of the invention, the proper pressure or compressive force to be applied to the surface **108** of the part **110** during the burnishing operation is provided by use of the pressure regulator **136**. As shown in **FIG. 10**, the pressure regulator **136** comprises a source of pressurized fluid **141** for providing pneumatic or hydraulic pressure against a piston **142**, diaphragm or other similar means. The piston **142** is coupled to the burnishing member **106** in such a manner that movement of the piston **142** operates to increase or decrease the force **F** being applied to the burnishing member **106** thereby increasing or decreasing the corresponding pressure being

exerted by the burnishing member **106** on the surface **108** of the part **110**. In operation, for constant pressure burnishing, the machine tool fixture moves the socket **102** in a predetermined pattern along the surface **108** of the part **110**. The control unit **132** functions with a feed back signal from the pressure sensor **130** to achieve closed loop control of the force **F** and the corresponding pressure being exerted on the surface **108** by the burnishing member **106**. It should now be apparent to those skilled in the art that by using the control unit **132**, the burnishing member **106** can be accurately moved in a selected pattern while exerting a predetermined pressure against the surface **108** of the part **110** to obtain a region having the desired residual stress distribution and magnitude of compression.

Conventional constant pressure burnishing apparatus require a containment means, such as end caps, for maintaining the burnishing member withing the apparatus. The containment means must be capable of withstanding high pressure and forces, including the time when the burnishing member is not in contact with the surface of the part. In the event that the containment means fails, the burnishing member could be propelled from the burnishing apparatus at high velocity. In contrast, the constant flow burnishing apparatus of the subject invention eliminates the need of a containment means that is capable of withstanding high pressure.

Referring to **FIGS. 11**, **12** and **13**, the burnishing member **106** may be selected from various materials having a higher yield strength than the part **110** being burnished and having a relatively high elastic modules to allow maximal deformation of the part **110**. In a preferred embodiment of the invention, the burnishing member **106** is formed from a high carbon steel or a sintered tungsten carbide containing a portion of a cobalt binder. The inner chamber **114** of the socket **102** is shown having a magnetic means **144**, such as a permanent magnet or an electric magnet or the like, which produce magnetic flux **145** (**FIG. 13**) that functions to maintain the burnishing member **106** withing the seat **112**. It

has been found that forming the socket **102** from a ferromagnetic alloy, such as a martensitic stainless steel AISI 440C, the socket **102** functions as a pole piece thereby increasing the holding power of the magnet means **144**. Because the bearing member **106** is supported by a low volume of fluid having a constant flow rate, the bearing member **106** will be retained within the socket **102** even while the fluid is flowing and the socket **102** is being repositioned or moved out of contact with the surface **108** of the part **110**.

Referring to **FIG. 14**, a blade of the present invention is shown, for use in turbo machinery. The blade **146** includes a generally rectangular platform **148**; an elongated airfoil **149** having a leading edge **150** and a trailing edge **152,** the airfoil **149** being rigidly attached to and extending radially outwardly from the platform **148**; and a root **154** rigidly connected to and extending radially inwardly from the platform **148** having a dovetail portion **155** for mounting to a rotor disk **156**. As used herein, the term "outwardly" refers to the direction away from the center of rotation of the blade and rotor disk and the term "inwardly" refers to the direction towards the center of rotation of the blade and rotor disk. The rotor disk **156** includes a plurality of circumferentially spaced axially disposed slots **158** therein. The blade **146** is attached to the rotor disk **156** by inserting the root **154** into a slot **158**. As shown, the root **154** and the slot **158** have complementing surfaces for securing the blade **146** to the rotor disk **156**. During operation, the rotor disk **156** and the attached blades **146** are subjected to high centrifugal loads that produce high dynamic stresses that may cause high cycle fatigue along portions of the rotor disk **156** and each blade **146**. Further, the leading edge **150** of the blade **146** is often subjected to damage by the impact of foreign objects in the fluid stream.

In a preferred embodiment of the invention, the blade **146** is treated by the method comprising a step or a combination of steps disclosed herein. In another preferred embodiment of the invention, the rotor disk **156** is treated by the method comprising a step or a combination of steps disclosed herein.

Another preferred embodiment of the invention, a part is selected from the group comprising automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like treated by the method comprising the step, or a combination of steps, of the present invention.

The method and apparatus for implementing the method of the subject invention utilizes a burnishing method that produces cold work and surface work hardening far less than either conventional shot peening, gravity peening, and conventional burnishing or deep rolling methods. The increase in residual compressive stress with minimal cold work developed by the subject invention penetrates to a greater depth than most conventional methods, such as shot peening and results in longer retention of compressive residual stress at elevated temperature, less rapid relaxation under cyclic loading, and minimizes the alteration of the residual stress field during tensile or compressive overload than conventional cold working and surface hardening processes. Further, the method for inducing a layer of compressive residual stress along the surface of a part and the apparatus for implementing the method provides control of the particular stress distribution and magnitude of compression that optimizes the fatigue performance of the part. By controlling the pattern of burnishing and by gradually reducing the magnitude of compression near the boundaries of the regions being burnished ("feathering"), the tensile zones which occur immediately adjacent and parallel to the boundaries may be reduced or eliminated.

Accordingly, the method and apparatus for implementing the method of the subject invention provides a relatively inexpensive and effective means of providing a compression force on a workpiece to induce compressive residual stress in a well defined localized region of a simple or complex part surface configuration with a minimum of cold working and surface hardening. By minimizing the amount of cold working and surface hardening, the method of the subject invention produces longer retention of compressive

residual stress at elevated temperature, less relaxation under cyclic loading, and minimizes the alteration of the residual stress field during tensile or compressive overload. Further, the method and the apparatus of the invention for inducing a layer of compressive residual stress along the surface of the part permits a variety of burnishing patterns to be designated to produce regions of residual stress that are appropriate for a specific engineering application. In addition, a part treated using the method of the invention have improved stress corrosion cracking resistance.

While the method and apparatus described constitute preferred embodiments of the invention, it is to be understood that the invention is not limited to the precise method and apparatus, and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

What is claimed is:

CLAIMS

1. A method of inducing a layer of compressive residual stress in the surface of a part comprising the steps of:

selecting a region of the part to be treated;

selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region;

exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress; and

varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface.

2. The method of Claim 1 whereby the pressure being exerted against the surface of the part is performed by a burnishing operation.

3. The method of Claim 1 wherein said pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 5.0 percent.

4. The method of Claim 1 wherein said pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 3.5 percent.

5. The method of Claim 1 further wherein the step of selecting the magnitude of compression includes the step of programming a control unit to automatically adjust the magnitude of compression being induced within the surface of the part.

6. The method of Claim 1 wherein the selected pattern along the surface varies the spacing between the zones of deformation.

7. The method of Claim 1 wherein the step of exerting pressure against the surface of the selected region includes the step of programming a control unit to control the application of said pressure.

8. The method of Claim 1 wherein the step of varying the pressure being exerted against the surface includes the step of inducing a more shallow layer of compressive stress within the surface of the part.

9. The method of Claim 1 further comprising the step of removing a layer of material along the surface being in low compression or tension.

10. The method of Claim 1 wherein the part is selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and parts for use in turbo-machinery.

11. A method of inducing a layer of compressive stress in the surface of a part comprising the steps of:

selecting a region of the part to be treated;

selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region;

programming a control unit to pass a burnishing member of a burnishing apparatus over the selected region in the selected pattern to produce a zone of deformation having a deep layer of compression within the surface; and

programming the control unit to increase, decrease or maintain the pressure being exerted against the surface at selected points along the selected pattern to obtain the desired residual stress distribution and magnitude of compression within the surface.

12. The method of Claim 11 wherein said pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 5.0 percent.

13. The method of Claim 11 wherein said pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 3.5 percent.

14. The method of Claim 11 wherein the burnishing apparatus comprises means for automatically adjusting the pressure being exerted against the surface of the selected region to increase on the high points and decreases on the low points encountered by the burnishing member along the surface of the part.

15. A method of inducing a layer of compressive stress in the surface of a part comprising the steps of:

selecting a region of the part to be treated;

selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region;

programming a control unit of a burnishing apparatus to perform a burnishing operation, the burnishing operation being performed along the selected region in a selected pattern to produce a zone of deformation having a deep layer of compression within the surface having associated cold working of less than about 5.0 percent; and

performing a second operation to induce a more shallow layer of compressive stress within the surface of the part to produce the desired stress distribution;

whereby said burnishing apparatus further comprising means for automatically adjusting the pressure being exerted against the surface of the selected region that increases on the high points and decreases on the low points that are encountered along the surface of the part during the burnishing operation.

16. A burnishing apparatus for inducing a compressive stress in the surface of a part comprising:

a burnishing member;

a socket having a inner chamber and a seat for receiving said burnishing member;

means for applying a force against said burnishing member for exerting pressure against the surface of the part; and

means for providing a constant volume of fluid to said inner chamber;

wherein said socket provides a clearance between said seat and said burnishing member for permitting the fluid to pass.

17. The burnishing apparatus of Claim 16 further comprising:

a pressure sensor for monitoring the fluid pressure; and

means for adjusting the force being applied against the burnishing member and the corresponding pressure being exerted by said burnishing member against the surface in response to the fluid pressure.

18. The burnishing apparatus of Claim 16 further comprising:

a programmable control means configured to continuously track the position of the burnishing member and for automatically adjusting the force being applied against the burnishing member and the corresponding pressure being applied against the surface by said burnishing member.

19. The burnishing apparatus of Claim 16 further comprising:

a programmable control means configured to direct the motion of said burnishing member in a selected pattern across the surface of a part.

20. A blade for use in turbo-machinery comprising:

a generally rectangular platform;

an elongated airfoil having a leading edge and a trailing edge, the airfoil being attached to and extending radially outwardly from said platform; and

a root attached to said platform and extending radially inwardly from said platform;

wherein said blade having been treated by the method of Claim 1.

21. The blade of Claim 20 further comprising the step of inducing a more shallow layer of compressive stress within the surface of the selected region.

22. The blade of Claim 20 further comprising the step of removing a layer of material along the surface being in low compression or tension.

23. A rotor disk for use in turbo-machinery comprising means for supporting a plurality of blades, wherein said rotor disk having been treated by the method of Claim 1.

24. The rotor disk of Claim 23 further comprising the step of inducing a more shallow layer of compressive stress within the surface of the selected region.

25. The rotor disk of Claim 23 further comprising the step of removing a layer of material along the surface being in low compression or tension.

ABSTRACT

The present invention is a novel method and an apparatus for implementing the method of inducing a layer of compressive residual stress along the surface of a part comprising the steps of selecting a region of the part to be treated; selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region of the part; exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress; and varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface.

FIG. 1

SELECT THE AREA OF PART TO BE TREATED

SELECTING THE DESIRED MAGNITUDE OF COMPRESSION AND RESIDUAL STRESS DISTRIBUTION

EXERTING PRESSURE AGAINST THE SURFACE OF THE SELECTED REGION, THE PRESSURE BEING APPLIED IN A SELECTED PATTERN ALONG THE SURFACE TO FORM ZONES OF DEFORMATION HAVING A DEEP LAYER OF COMPRESSIVE STRESS

VARYING THE PRESSURE BEING EXERTED AGAINST THE SURFACE TO PRODUCE THE DESIRED RESIDUAL STRESS DISTRIBUTION AND MAGNITUDE OF COMPRESSION WITHIN THE SURFACE

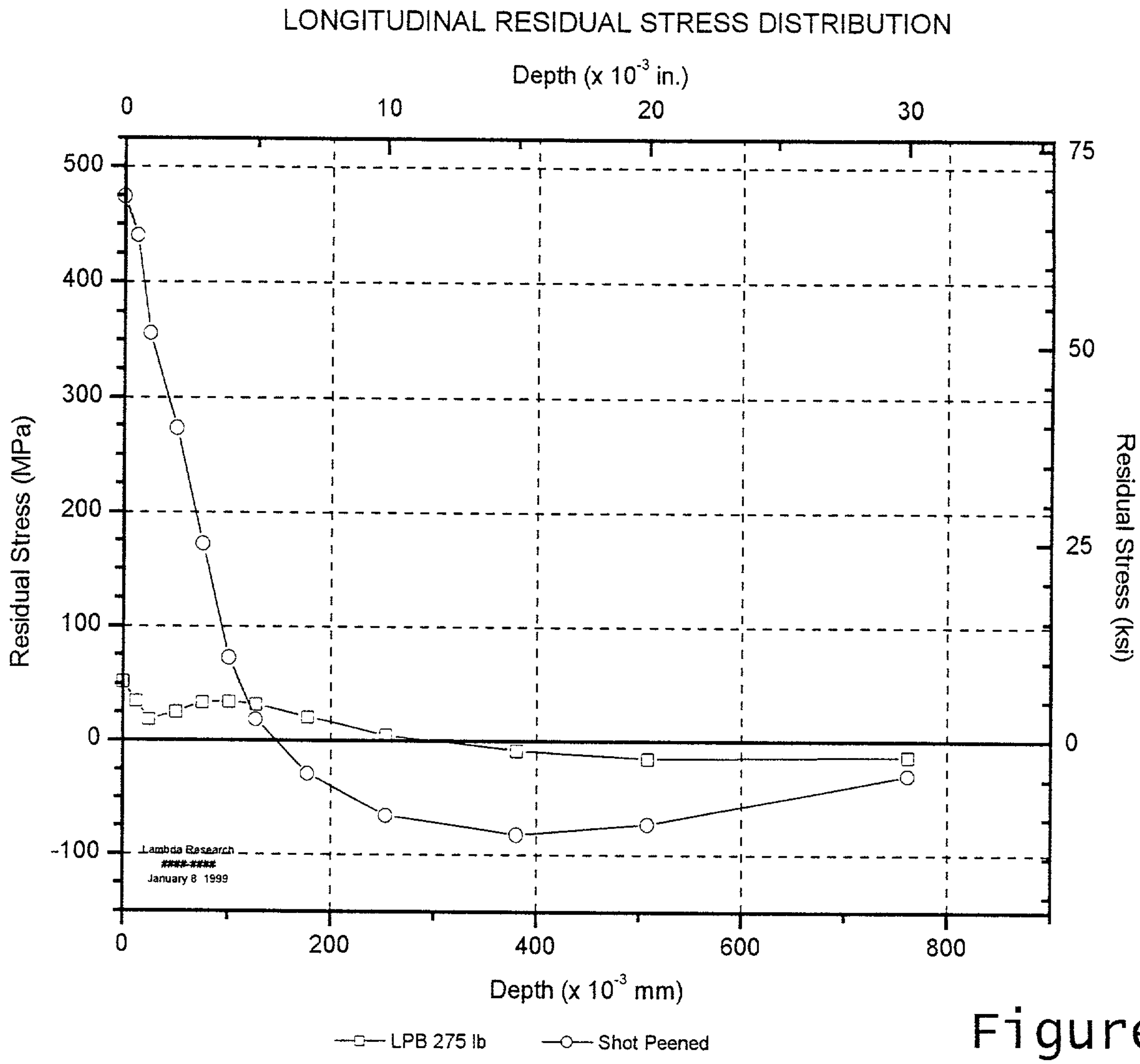


Figure 2

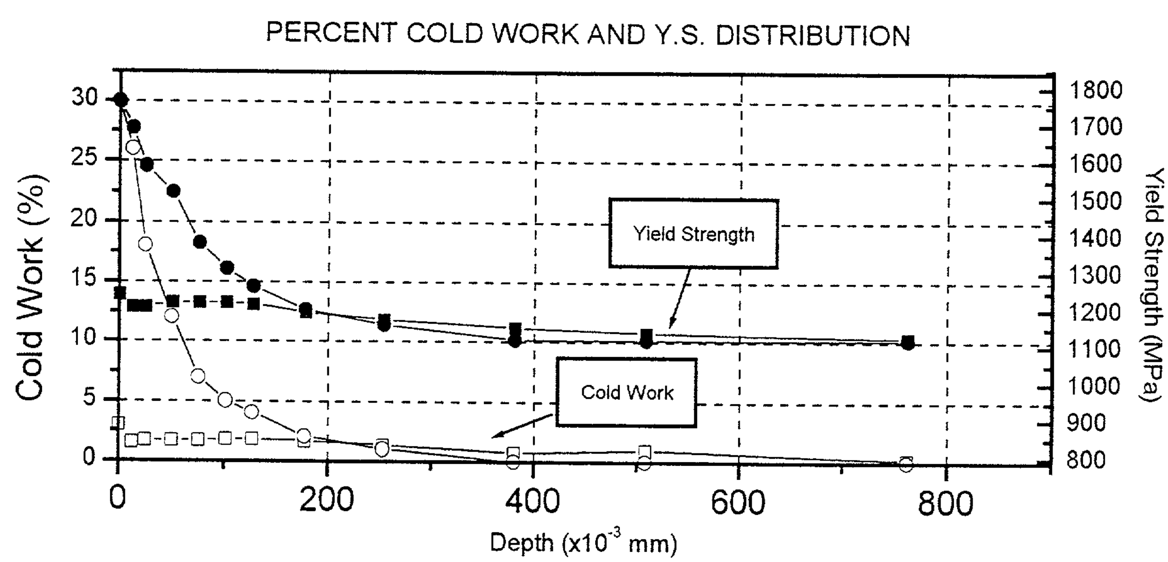


Figure 3

Fig. 4

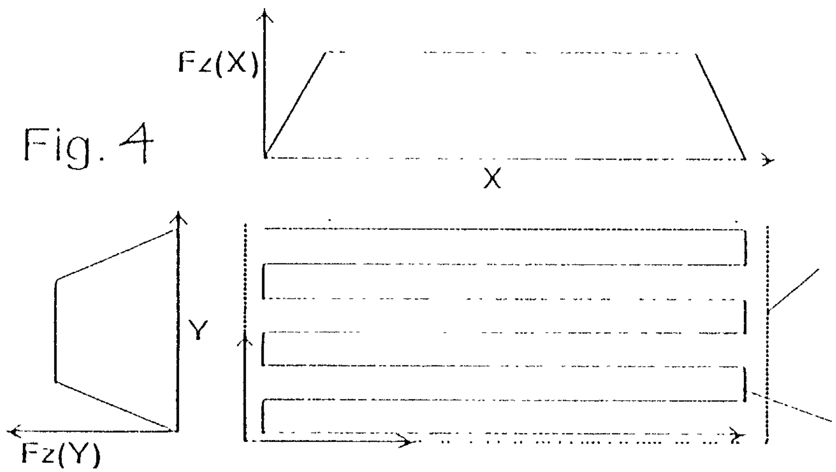
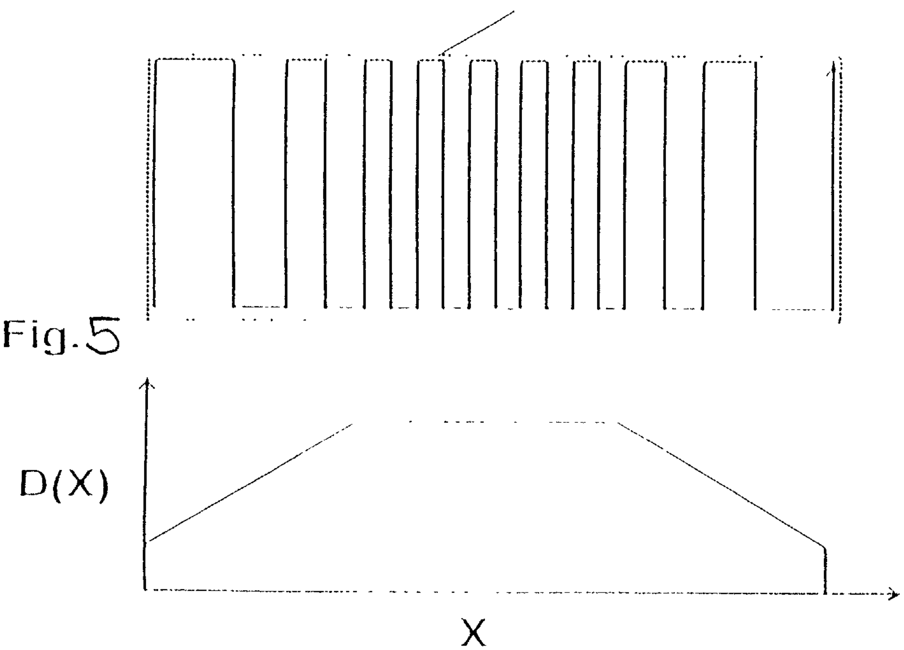


Fig. 5



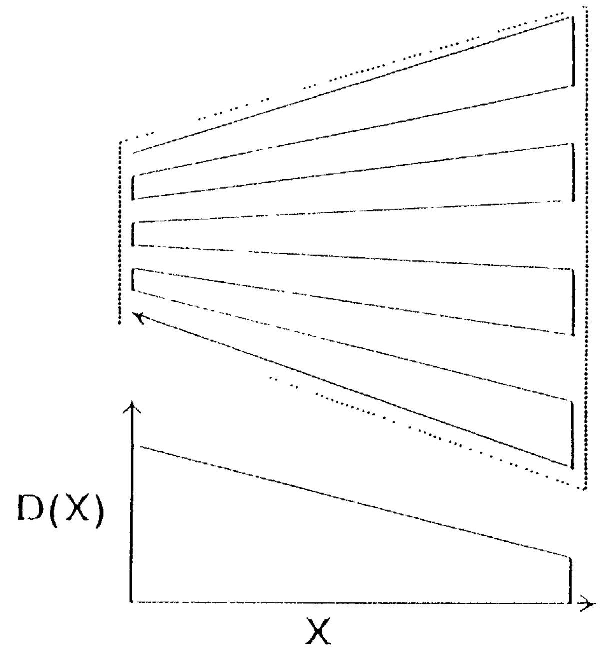


Fig. 6

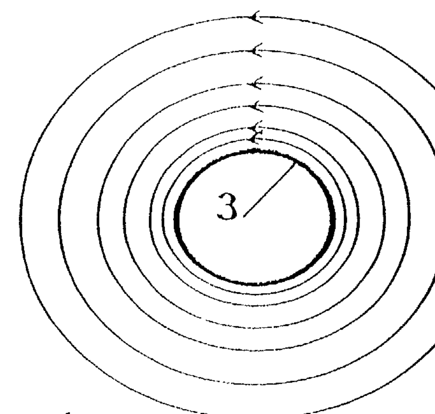


Fig. 7

RESIDUAL STRESS DISTRIBUTION

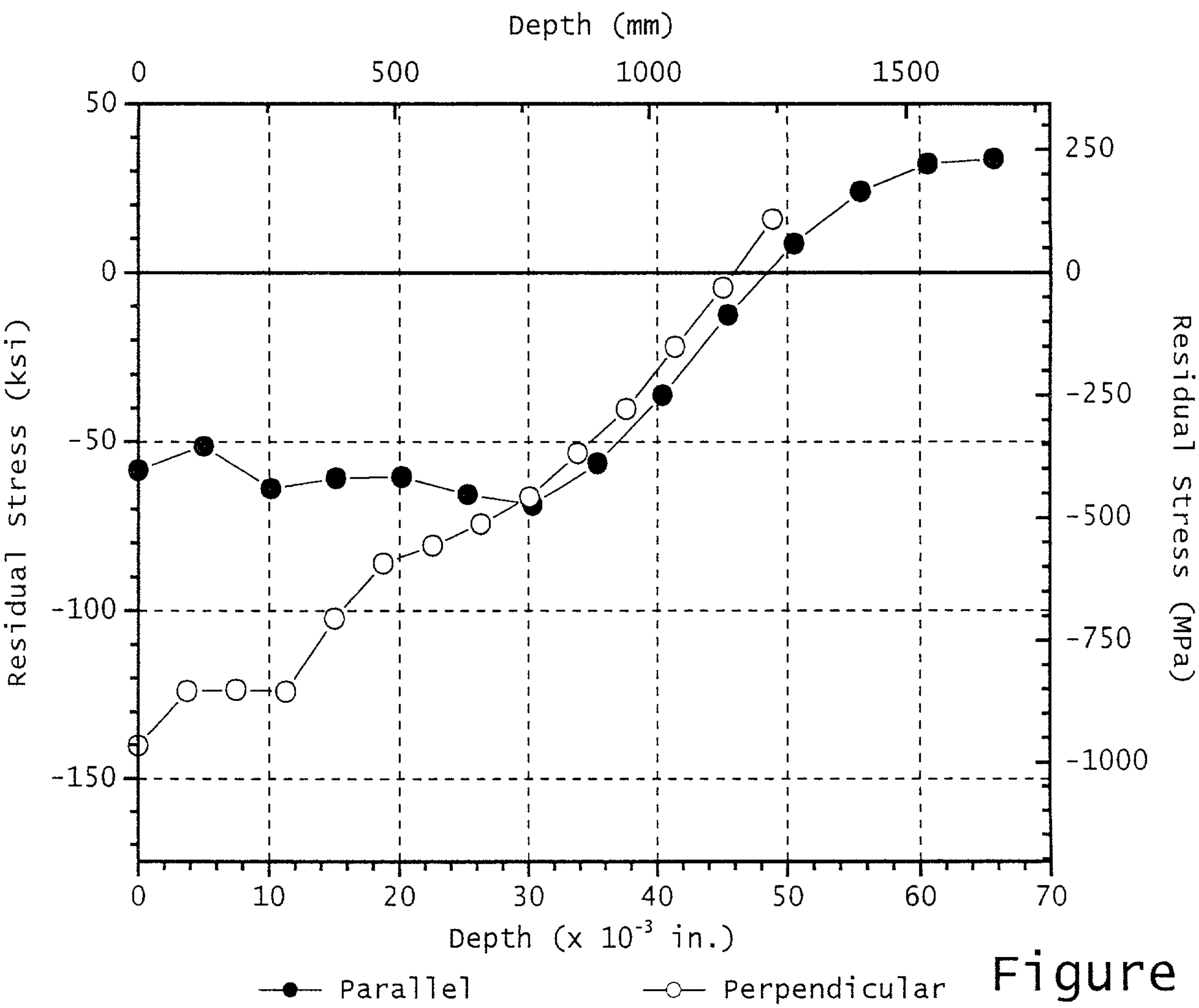
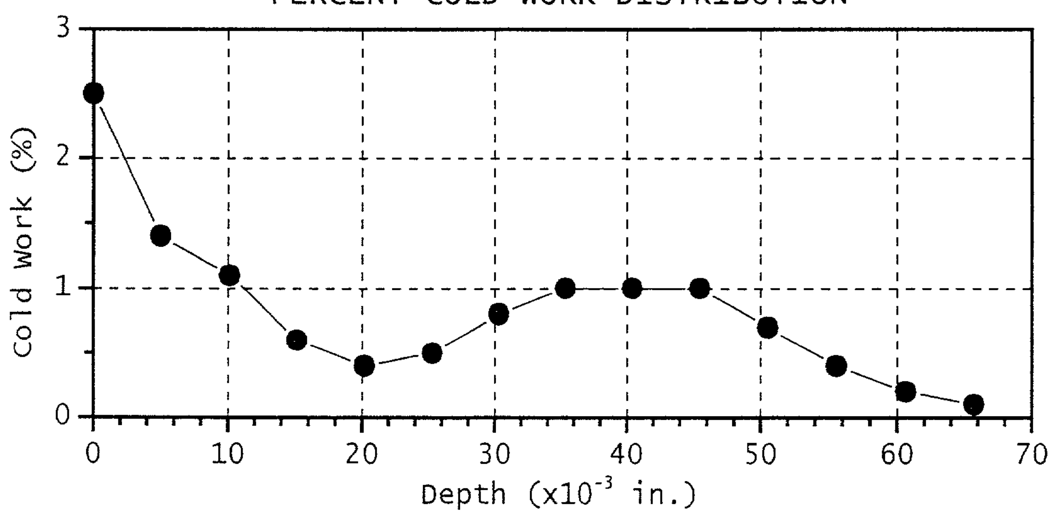


Figure 8

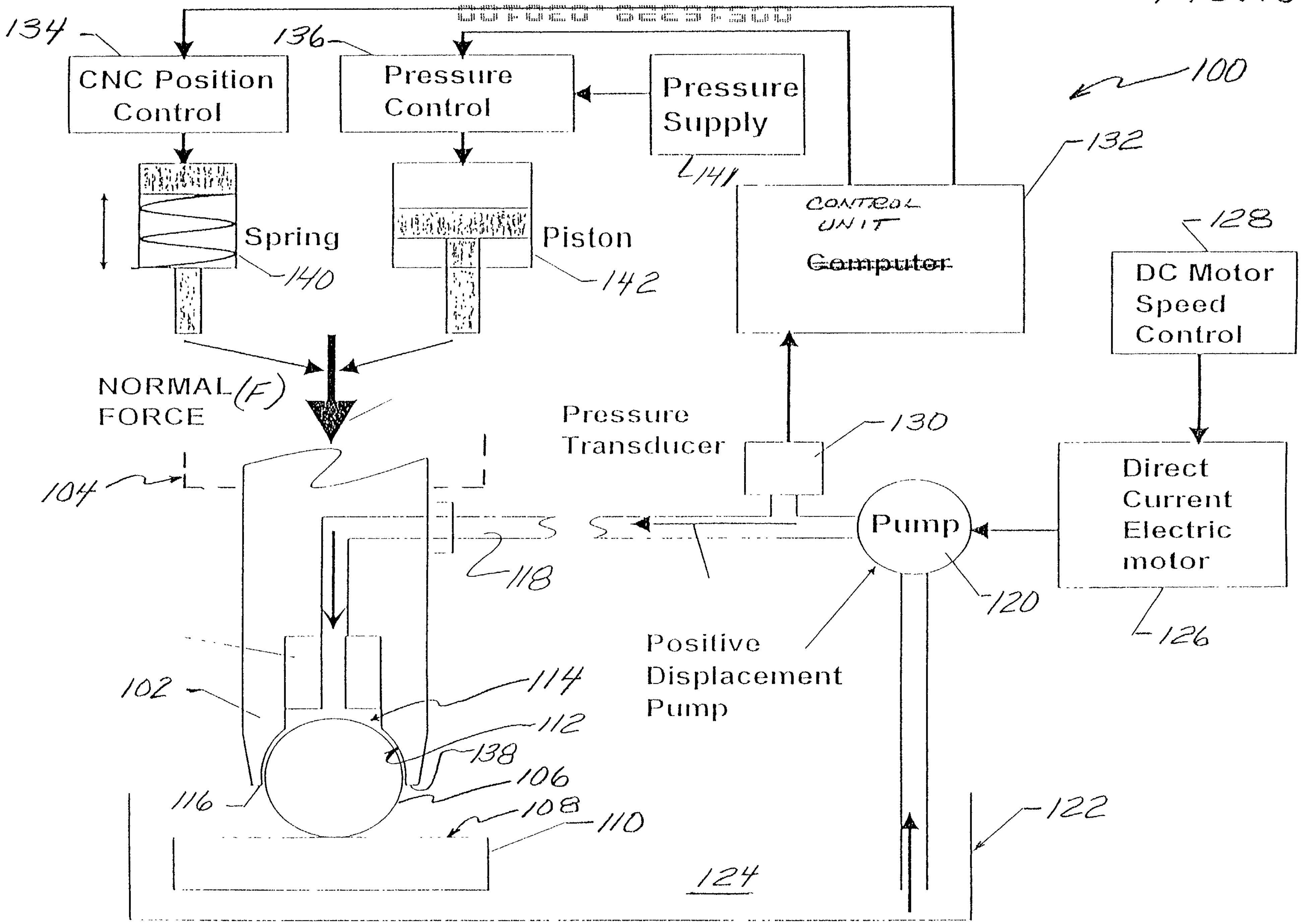
PERCENT COLD WORK DISTRIBUTION



4340 STEEL LPB COUPON

Figure 9

FIG. 10



100
134
CNC Position Control
136
Pressure Control
Pressure Supply
141
132
CONTROL UNIT
~~Computer~~
128
DC Motor Speed Control
Spring
140
Piston
142
NORMAL FORCE (F)
104
Pressure Transducer
130
Direct Current Electric motor
Pump
118
120
126
Positive Displacement Pump
102
114
112
138
106
116
108
110
122
124

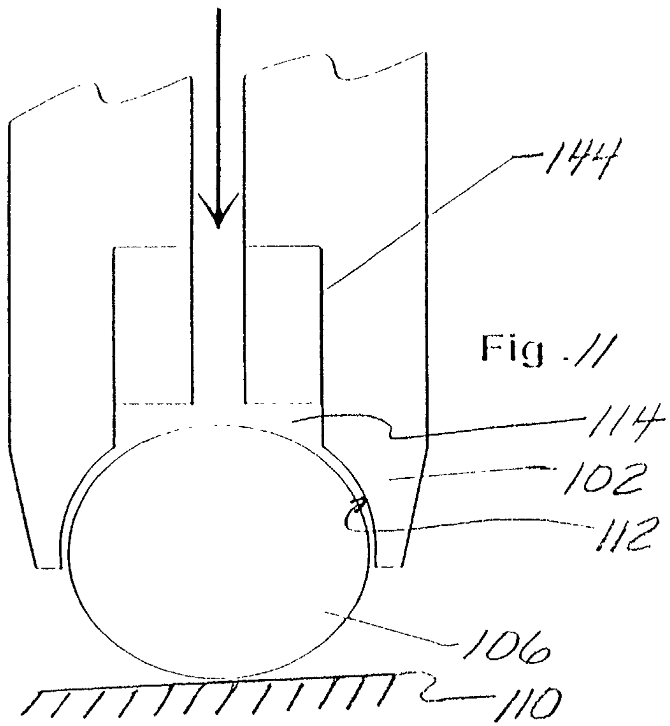


Fig. 11

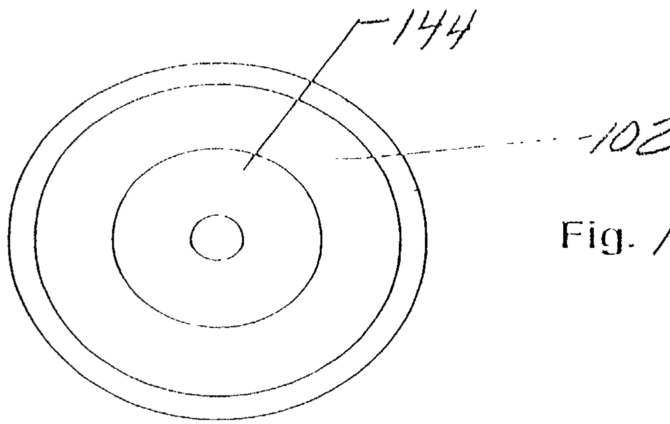


Fig. 12

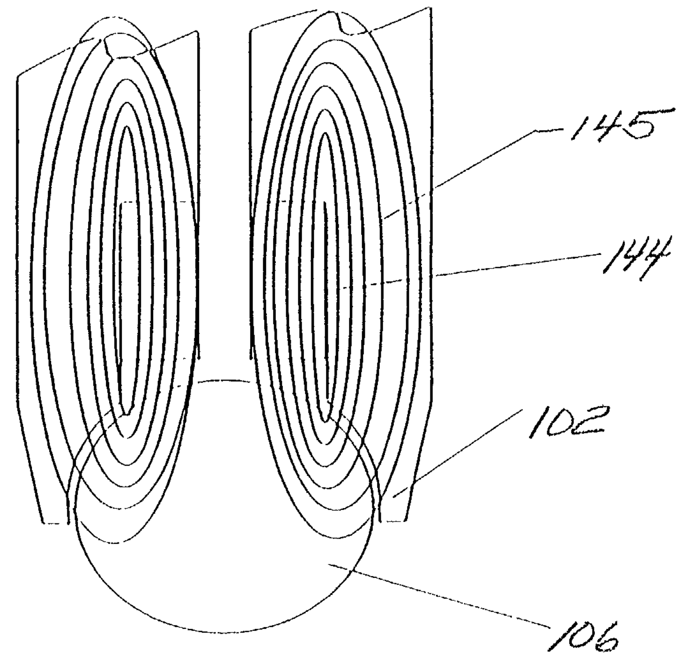
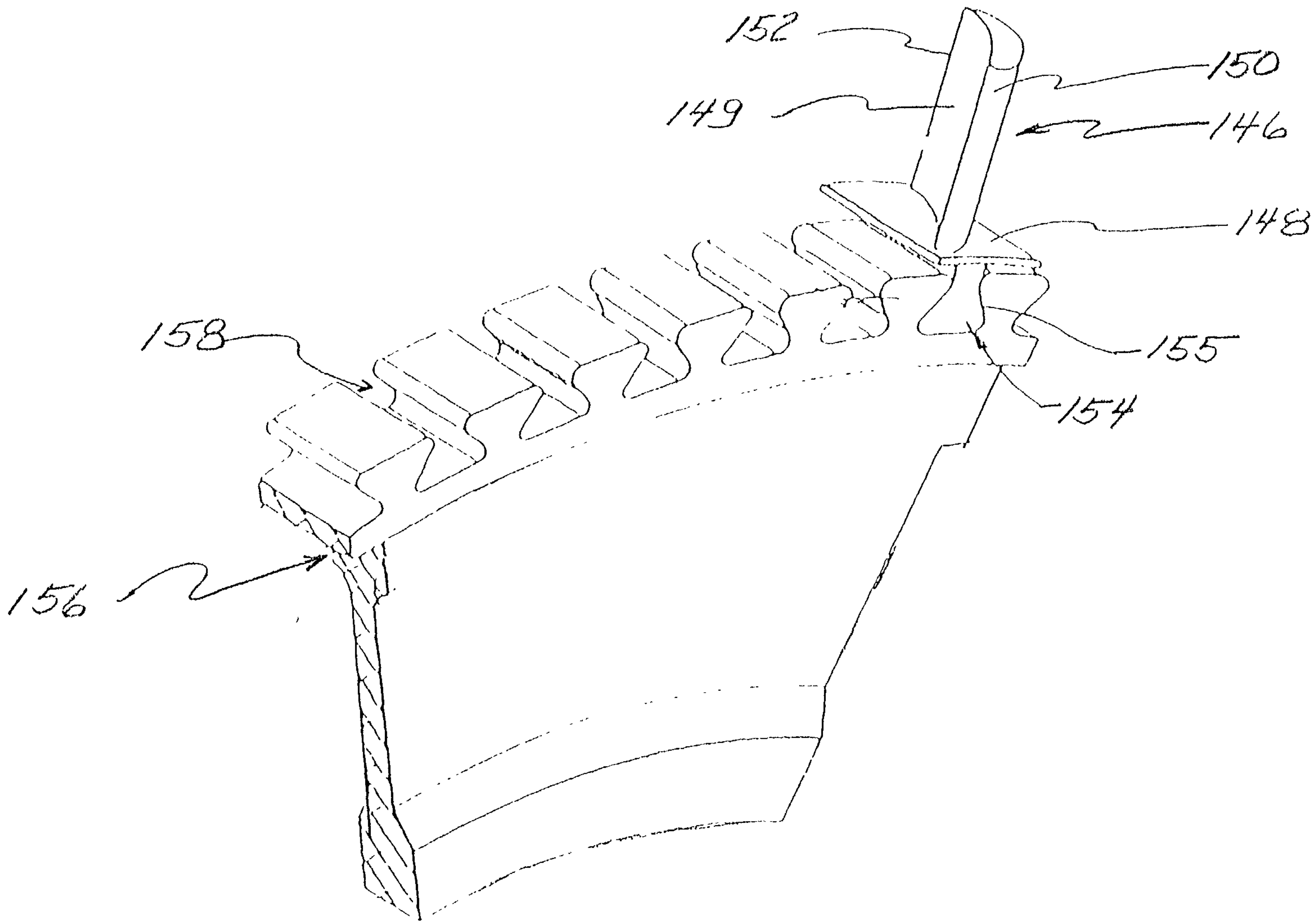


Fig. 13

FIG. 14



PATENT

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below, next to my name; that I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter that is claimed, and for which a patent is sought on the invention entitled: **METHOD AND APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART** (Attorney Docket No. LRI-003PAT), the specification of which is filed herewith in the United States Patent and Trademark Office; that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above; that I acknowledge the duty to disclose information, which is material to patentability as defined in 37, Code of Federal Regulations, Section 1.56, and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent; that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY

I hereby appoint the following attorneys to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: Mark F. Smith (Reg. No. 32,437) and Eric W. Guttag (Reg. No. 28,853). Send all correspondence to:

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